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THE BIO-ENVIRONMENTAL INDICES PROJECT: AN OVERVIEW

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INTRODUCTION

Industry and government are increasingly faced with difficult resource management decisions. To achieve ecologically sustainable development, other issues such as the conservation of biodiversity must now be considered alongside wood production. Analysis of non-wood values such as biodiversity presents some difficult operational problems for forest planners and policymakers. How can biodiversity be defined and which components are most important? How does their conservation impinge on wood production?

The Bio-environmental Indices Project (BIP) is an initiative of the Canadian Forest Service – Ontario Region. The ultimate aim of the project is to develop empirical approaches for examining the *production possibilities for, and trade-offs between, wood production and biodiversity conservation*. To do so, the BIP will use available data on climate, terrain, and soil parent material; biological site data; mathematical models; and Geographical Information Systems (GIS) technologies.

The BIP is being undertaken in close collaboration with several federal, provincial, and international institutions. Major cooperators include the Ontario Ministry of Natural Resources (OMNR, including the Ontario Forest Research Institute and the Integrated Natural Resource Information System initiative), Environment Canada's Canadian Wildlife Service, Agriculture Canada's Biological Resources Division, the Centre for Resource and Environmental Studies at the Australian National University (CRES, ANU), and a number of Canadian Forest Service scientists. Core funding has come from the Northern Ontario Development Agreement's (NODA) Northern Forestry Program and the OMNR's Sustainable Forestry Initiative.

FOREST PLANNING AND BIO-ENVIRONMENTAL INDICES

A variety of tools has been developed to support forest planning. These range from simple calculations to determine harvest levels (e.g., MAD – Maximum Allowable Depletions) to more complicated computer models such as FORMAN, HSG (Moore and Lockwood 1990), and FORPLAN (McKenney 1990). The advent of GIS technology has also greatly enhanced the capabilities of planners to examine the implications of alternative management strategies. However, for the most part, the use of these tools has focused around the provision of wood. The supply of non-wood values such as biodiversity has generally not been explicitly considered in standard forest planning tools. There are several reasons for this. Non-wood services are in many respects more difficult to define and quantify. Also, the demand to include some of these values is relatively new.

In an operational sense, the BIP is developing methods to assess the *relative* contribution particular landscapes make to both the conservation of biodiversity and the supply of wood. It will then be possible to estimate for a given location both the opportunity costs, in terms of wood foregone, of favoring ecological conservation, and a measure of the ecological opportunity costs of harvesting. In many cases, trade-offs need not be a matter of all or nothing; rather, various scenarios must be explored to resolve competing objectives.

Spatial Indices of Biodiversity

Biodiversity is an umbrella concept that relates to a range of biological and ecological phenomena. It includes genetic, species, and ecosystem diversity. The BIP will be



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developing spatial models that encompass these concepts based on the following *bio-environmental indices*:

Habitat suitability: This index will provide a measure of how suitable a landscape is for a species. Predictions will be made of the probability of occurrence or potential distribution of selected tree species and animals (Austin *et al.* 1984, Booth 1985, Nix and Gillison 1985, Norton *et al.* 1992, and Mackey 1993). The potential distribution of vegetation associations will also be predicted (e.g., those recognized by forest ecosystem classifications [FEC] such as that of Sims *et al.* 1989).

Taxonomic diversity: Diversity indices will be calculated in the BIP using a range of taxonomic and spatial units (e.g., the number of potential FEC types per km, number of potential songbird habitats per watershed).

Representativeness: The conservation of biodiversity requires that a representative sample of ecosystems be identified and protected through some form of reservation system or management framework. The BIP will be generating environmental domain classifications for the province to provide a context and framework for assessing ecosystem representativeness (see Mackey *et al.* 1989).

Wilderness quality: Indices will be derived that provide a measure of the wilderness quality of landscapes. These can be generated in a systematic and explicit manner in a GIS framework as a function of naturalness (e.g., disturbance history, such as past logging practices) and remoteness from settlement and access (see Lesslie *et al.* 1988).

Spatial Indices of Wood Supply

The data (indices) identified above will be matched with spatial estimates of standing and potential wood supply. Standing wood supply will be examined using the Canadian Forest Resource Data System, the OMNR Forest Resource Inventory System, and the Price Responsive Timber Supply Model (PRTSM) database (see Messmer and Booth 1992). PRTSM utilizes inventory data, delivered wood costs, roundwood values, and user-supplied price projections to estimate the potential economic supply of roundwood to the forest products industry.

Potential wood supply will be modeled using existing growth and yield estimates and through new analyses of existing growth and yield field observations.

Database Development

Considerable effort must be invested in database development if reliable spatial analyses are to be undertaken. Certain methodological advances in environmental and spatial analysis provide opportunities to better quantify some components (or production possibilities) of biodiversity. The conceptual approach has its roots in land evaluation and crop modeling for agriculture and utilizes

mathematical modeling techniques to generate reliable spatial estimates of previously intractable environmental variables. These data can be used to generate landscape models of the *physical determinants* of biological phenomena. These determinants can be defined in terms of four *Primary Environmental Regimes (PERs)*: (1) *radiation*, (2) *thermal*, (3) *moisture*, and (4) *mineral nutrient*. Data on climate, terrain, and soil parent material are the basic inputs to modeling these regimes across landscapes. This modeling framework provides an empirical approach to making spatial predictions about the potential response of plants and animals to the abiotic environment. There is now an enhanced capacity to extrapolate, across entire landscapes, information gained from analysis of field-based observations.

An example is shown in Figure 1. This illustrates some preliminary analysis from Mackey and Sims (1993). The response of four tree species to a single climatic variable, mean daily temperature for the hottest consecutive three months, is shown. This analysis is based on a sample of 2,100 forest plots collected as part of the Forest Ecosystem Survey in northwestern Ontario (Sims *et al.* 1989). Estimates of climate were generated at each survey location using the ANUSPLIN/BIOCLIM climate interpolation procedure (Nix and Gillison 1985, Nix 1986, Hutchinson 1987). Three distinctive thermal responses can be observed: the responses of black spruce and trembling aspen are very similar across the entire range; largetooth aspen is dominant at the warmer end; and red pine occupies an intermediate thermal domain. A spatial prediction of these thermal responses can then be made by coupling each species' profile to gridded estimates of the climatic parameter.

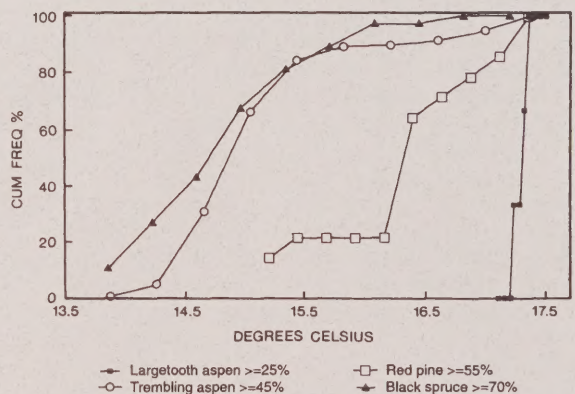
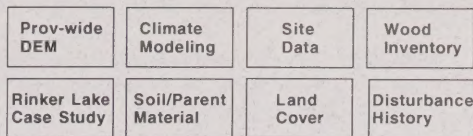


Figure 1. Plot of the response of four tree species in northwestern Ontario to the mean temperature for the warmest consecutive three months (i.e., mean daily summer temperature). Temperature was estimated at the point of survey for 2,100 forest plots (R. Sims, Canadian Forest Service, Sault Ste. Marie, Ontario, personal communication). The cumulative frequencies are based on plots where species are dominant as determined by observed percentage canopy cover.

Phases of the Bio-environmental Indices Project

I) Primary Database Development



II) Bio-physical and Ecological Modeling

- Analysis of Site Data & Spatial Predictions

III) Decision Support Tools & Ecological Economics

- Bio-environmental Indices and Trade-off Analyses

Figure 2. Overview of the Bio-environmental Indices Project.

The BIP will be developing databases and undertaking analyses for the whole province in collaboration with several partners. Figure 2 summarizes the phases of the project. In the first phase a *primary database* will be developed that comprises:

- (1) a digital elevation model (DEM)
- (2) climate surfaces
- (3) various biological site data
- (4) wood inventories
- (5) the Rinker Lake case study
- (6) geological data on soil parent material
- (7) extant land cover
- (8) disturbance history

The province-wide perspective provides the context needed to assess the contribution of any particular forest stand or landscape to the conservation of biodiversity. For example, in the old-growth forests controversy, the ecological importance of any one stand is contingent on the degree to which it is similar or dissimilar to other stands. Similar analogies can be drawn for other biodiversity conservation issues (e.g., rare, threatened, or endangered species). The importance of a given stand for wood supply also requires information about alternative sources of wood if conflict between competing values is to be reduced.

A major part of the BIP's collaborative efforts involves the collection and compilation of various site-based forest data (e.g., FEC, growth and yield, wildlife). The site data will be reanalyzed statistically with estimates of values for the primary environmental regimes appended to each plot location. The spatial database of these values and newly derived functions will form the basis for spatial predictions.

Underpinning the province-wide analyses will be a number of finer-scaled case studies. These are intended for trade-off analyses at a more operational level and for evaluating the error involved with some of the broader-scaled analyses.

As shown in Figure 2, Phase II involves statistical analysis of the various site data and spatial extension of the environmental relations (secondary data). Phase III involves the trade-off analyses and the development of decision support tools.

Database Management and Technology Transfer

An array of GIS-related computer programs are needed to undertake the database development and analyses required by the BIP. Figure 3 indicates the major software involved and the flow of data between them. The BIP uses both workstation and PC hardware platforms. A GIS package called GRASS is the "hub" of the BIP workstation efforts, while IDRISI is the PC hub. These GIS packages can easily interface with other commercial software packages. In addition to the many spatial analyses performed, these software also provide the mechanisms for database management and housekeeping functions on the very large data files the project requires. They also provide a convenient means of displaying spatial data and the results of analyses.

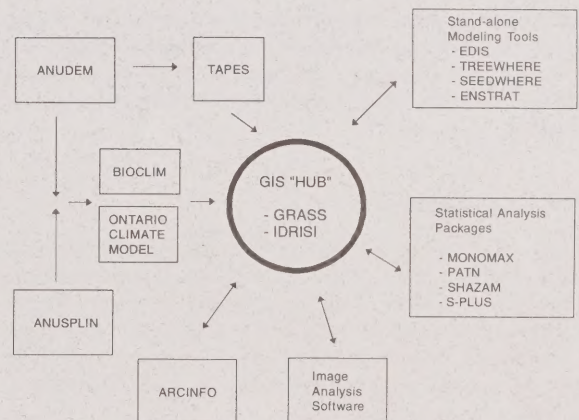


Figure 3. Illustration of the various computer programs being developed and integrated for the Bio-environmental Indices Project. Some of the programs are commercial packages, others are existing research tools for analyzing data within a modeling framework. New decision-support tools are also being developed.

The development of the climate surfaces and digital elevation models for Ontario require several computer programs (ANUDEM, ANUSPLIN, and BIOCLIM). Results from ANUDEM (Hutchinson 1989) and ANUSPLIN feed into the BIOCLIM program to produce gridded estimates of climatic parameters. These become spatial data for GRASS. The elevation grids produced by ANUDEM also feed into the TAPES program (Terrain Analysis Program for the Environmental Sciences, Ian Moore, CRES, ANU). This program calculates a number of secondary and compound terrain attributes on a regular grid, thereby producing additional spatial data. The results of the statistical analyses of site data will generate secondary spatial data such as the potential distribution of species or FEC types.

A number of statistical packages will be used, including MONOMAX (Bayes and Mackey 1991), PATN (Belbin 1987), and SHAZAM (White *et al.* 1990).

The BIP is producing several customized PC software programs to undertake particular analyses. Environmental Domain Interrogation System (EDIS), TREEWHERE, and SEEDWHERE will take primary and secondary spatial data from GRASS, perform specific calculations and generate outputs for particular problems. EDIS will use the environmental domain classifications to assess the representativeness of a network of sites or polygons. This will be useful for establishing research plots and/or assessing the adequacy of ecological reserves. TREEWHERE will facilitate access to the spatial models of plant suitability. SEEDWHERE will assist in the management of seed movement, i.e., what areas have a climate similar to the source location of a particular seedlot, or, where can I search for seed that is genetically adapted to a particular climatic envelope? ENSTRAT (Environmental Stratification) will help users interrogate spatial databases to find potential sites for research or monitoring plots.

Technology transfer is an important component of the project. Several workshops, reports, and user's guides are planned over the course of the next 2 to 3 years. These will occur in close collaboration with our partners to ensure maximum impact.

CONCLUSIONS

In a number of respects, forestry in Ontario can be considered as *data rich* but *information poor*. Various computer-based techniques now provide opportunities to analyze much of these data in a more quantitative and explicit modeling framework to generate useful information. The BIP, together with its many collaborators, aims to make a contribution to this task.

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